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Borehole Jack Test for Determination of Modulus of Deformation of Rock Mass — Code of Practice

ICS 93.020

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Rock Mechanics Sectional Committee, CED 48

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Rock Mechanics Sectional Committee had been approved by the Civil Engineering Division Council.

Erection of civil engineering structures in or on the rock requires the properties of rock and rock mass. The characteristics of intact rock differ greatly as compared with the rock mass which contains discontinuities in the form of joints, folds, minor/major shear, faults, etc. Discontinuities govern the rock mass properties to a great extent. These rock discontinuities adversely affect the stress-deformation behaviour of rock masses. The deformation modulus of rock mass is dependent on the number and orientation of joint sets; aperture of joints; type and extent of infilling material; presence of shears; water conditions; weathering, etc. Laboratory testing on intact rock samples do not take into account the effect of discontinuities, therefore, field tests are required for representative and realistic assessment of properties of rock mass.

Number of methods exist for the determination of *in-situ* modulus of deformation with deformation measurement on the loading surface and away from the surface. IS 7317 'Code of practice for uniaxial jacking test for deformation modulus of rock mass' covers the determination of modulus of deformation of rock mass with surface and sub-surface measurements of deformations. Borehole jacks are used for the assessment of deformation modulus of rock in deep drillholes. The test helps in defining the stress-deformation behaviour of sub-surface rock mass in the preliminary investigation stages when exploratory drilling is carried out to decipher the geological conditions beneath the foundation. Further, the test is also useful in studying the anisotropy in rock mass as it can be used in horizontal, vertical or inclined drillholes. Additionally, the jack can be oriented in a specified direction inside a drillhole also. The rigidity of the borehole jack depends on the loading platens and number of pistons. This standard covers procedure and method of interpretation of modulus of deformation of rock mass in an NX size (76 mm diameter) drillholes in rock.

The composition of the Committee responsible for the formulation of this standard is given in Annex A.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be same as that of the specified value in this standard.

Indian Standard

BOREHOLE JACK TEST FOR DETERMINATION OF MODULUS OF DEFORMATION OF ROCK MASS — CODE OF PRACTICE

1 SCOPE

1.1 This standard covers the determination of modulus of deformation of rock mass by borehole jack test at different depths and directions in NX size drillhole of 76.2 mm diameter. The stress is applied through two curved steel platens covering a 90° sector over a length of 203 mm. The applied stress and resulting deformations of rock mass are used for the determination of modulus of deformation of rock mass using appropriate elastic theory. The modulus of deformation of rock mass depends on the applied stress level and thus, it is not a constant parameter which means it cannot be characterised by a unique value. The modulus of deformation of rock mass is recommended based on the stress levels anticipated on account of the proposed structure and thus becomes an engineering judgement.

1.2 Creep characteristics may be studied keeping the uniform stress level for a specified period and then deformation *versus* time curve is plotted to analyse behaviour of rock mass under sustained loading.

1.3 Anisotropy can also be determined by application of stress level in desired directions in relation to the bedding or any other prominent joint or the design requirements suiting the proposed structure.

2 REFERENCE

The standard listed below contain provisions which, through references in the text, constitute provisions of this standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
4464 : 1985	Code of practice for presentation of drilling information and core description in foundation investigation

3 SELECTION OF TEST SITE

3.1 Before selection of site for testing, geological information is needed to be compiled. Geological sections of the entire area under the zone of consideration should be mapped. Geological map indicating the different lithological units and structural zones should be prepared. In each of these similar zones, at least five tests should be conducted. The number of tests may be increased in the event of large variation in results and direction of application of stress to confirm the findings.

3.2 The drillhole locations shall be selected so as to obtain detailed information about the sub-strata. Location and number of drillholes for testing should be selected keeping in view the variability in geology and type of structure.

3.3 Drillholes for conducting the tests should be selected so as to cover the prominent rock types for proper representation of geological formation including weak rocks too. The geological logs of all the drillholes shall be prepared for rock mass characterisation.

3.4 Tests in massive and fractured zones should be conducted to study the effect of discontinuities. However, highly fractured or shear zones can be avoided to reduce the risk of damage to the borehole jack. Testing in such zones may result in differential deformation of loading platens, thus leading to damage to the borehole jack. In extreme cases, the jack may get struck inside the drillhole, therefore borehole logs and drillhole cores should be studied and inspected in detail before finalizing the test sections.

4 DRILLING OF DRILLHOLES

4.1 The NX size drillhole of 76.2 mm diameter size should be drilled using rotary drilling. The quality and condition of the drilling bits should be assured so as to maintain the appropriate size of the drillhole. All efforts should be done to get good core recovery. The test section shall have to be decided based on the rock cores obtained from the drillhole. The cores obtained from drilling can be used in laboratory testing for assessment of various properties; therefore, good drilling practices should be adopted. In case of jointed or poor rocks, triple core barrel can be employed. Vibrations in drilling machine is another factor affecting the core recovery, hence, drilling machine should be anchored firmly before start of the drilling activity. Quality of diamond bits and condition of drilling machinery affect the core recovery and the size of the drillhole. Quality of drilling also depends on the condition of cutting bits and the experience of drill operator. The improper size and inferior quality of core bits should be avoided.

4.2 There is possibility of collapsing of the drillhole in the overburden material or fractured zones. Hence, mild steel casing of appropriate size shall be installed in the overburden portion or fractured rock mass.

4.3 For presentation of drilling information and core description, IS 4464 may be referred. The details of project, structure, RD, elevation, depth, orientation of drillhole, etc, shall be recorded in the register and written with paint or permanent marker on the core boxes for identifications. Apart from this, the details about the drilling rate, length of core run, type of cuttings and quantity of water loss in drilling shall also be recorded.

4.4 The records of permeability tests in the drillhole shall also be recorded in proper formats.

4.5 Geological logs of all the drillholes should be prepared by the concerned Engineering Geologist in standard format.

4.6 Drillhole shall be properly capped after completion of drilling work for protection.

5 TEST SET-UP

5.1 Test set-up shall include the following:

a) Borehole jack unit which includes jack comprising two curved stiff stainless steel plates which can be pulled apart by hydraulic pressure, LVDTs mounted on the jack, end couplings for pressure and retraction lines and electrical signal or LVDT cable.
b) Dual acting hydraulic pump of suitable capacity and capable of retraction also.
c) Pair of hydraulic hoses for inflation and deflation of borehole jack as per the test depth requirement.
d) Electrical cable for transmitting rock deformations to the readout unit.
e) Quick connecting couplers.
f) Pressure gauge.
g) Deformation measuring read out unit.
h) Data-logger or Data acquisition system, if any.
j) Tripod stand with chain pulley arrangement. Tripod stand can be avoided in small drifts and testing in shallow drillholes.
k) MS casings of BX size; in the event of non-availability of BX casing, any other hollow casing with similar diameter can also be used with suitable connection between jack and casing.
m) Drilling tools like pipe wrenches, clamps, etc.

5.2 A sketch showing the drillhole and equipment setup is given in Fig. 1.

6 TEST PROCEDURE

6.1 Tests should be conducted after completion of drilling work without wastage of time due to the following reasons:

a) Drillhole may collapse at a subsequent time.
b) Weathering of rock may affect the resultant deformations of rock, thus affecting the deformation modulus.
c) Availability of accessories like tripod stand, drilling machines, drilling crew, etc is ensured.
d) Testing can be done at faster pace with the use of drilling machine and crew.
e) Safety of the equipment and manpower can be ensured.

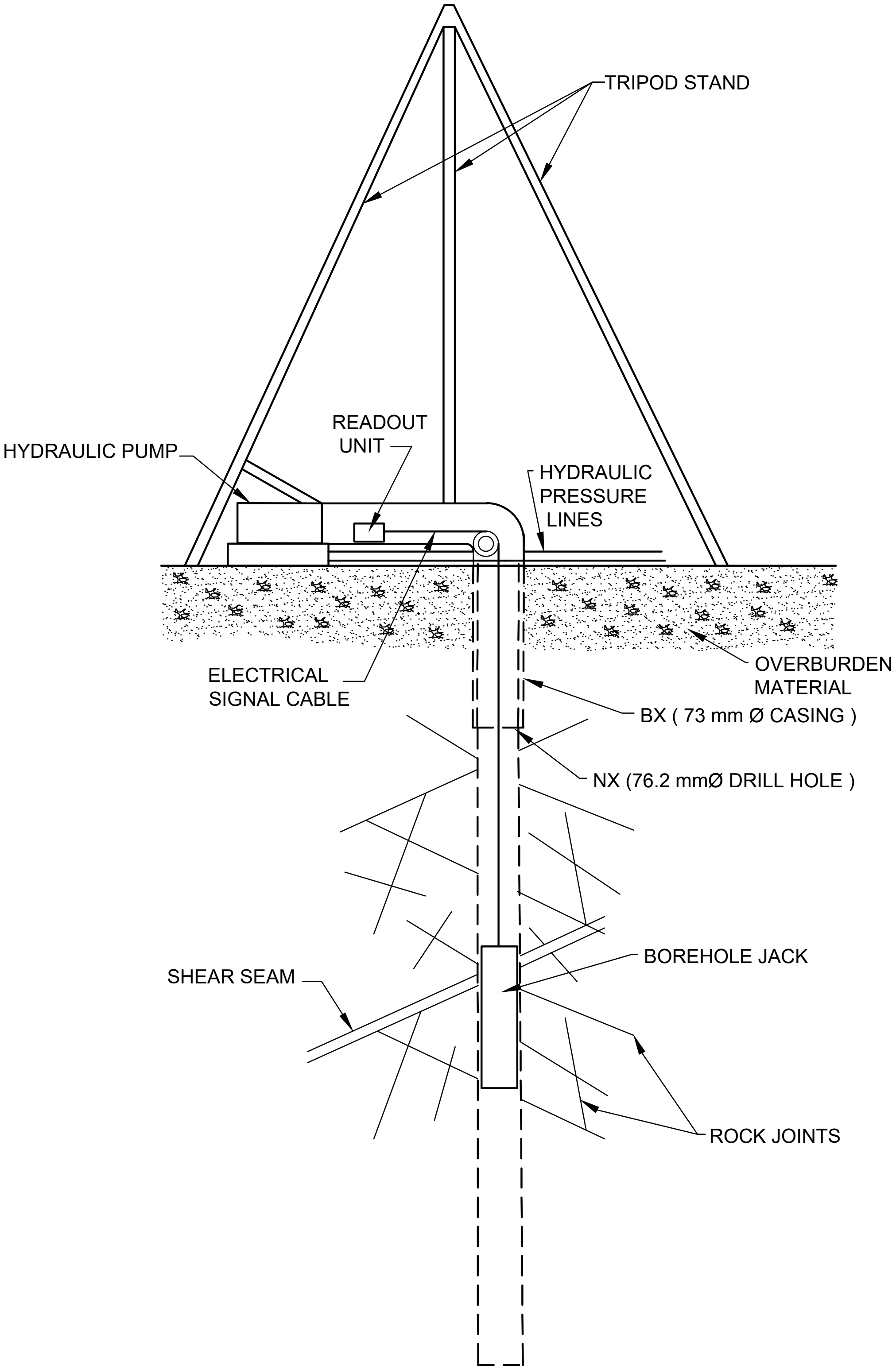

Fig. 1 Equipment Set-Up and Accessories

6.2 The borehole jack should be test checked before installation in the drillhole.

6.3 Calibration of the borehole jack should be done prior to the commencement and after the completion of tests. In case of large number of tests being undertaken, mid-way calibration can also be done.

6.4 Washing of drillhole with clean water should be done for removal of protruding loose rock pieces, if any which may otherwise obstruct the movement of borehole jack. Clay or gaugy particles present in the joints also get washed away which may otherwise clog the borehole jack.

6.5 Drillhole log shall be studied for variability in rock mass before selecting the test locations. Cores should always be inspected to select the test locations. Sections containing shear and highly fractured zones should be avoided as there is risk of borehole jack getting struck due to loose infilling material entering the jack or large deformations exceeding the prescribed limits of the equipment.

6.6 The rock mass should desirably be uniform in at least 400 mm length so as to avoid differential deformations which may otherwise damage the borehole jack.

6.7 The distance between two consecutive tests in a drillhole should be kept to a minimum of 400 mm and preferably 500 mm for undisturbed sections.

6.8 The jack is connected to the BX casing (73 mm diameter) and lowered at the specified depth.

6.9 The direction of load applications can be adjusted by rotating the jack to study the anisotropy in rock. For orientation of jack in any specified direction, a continuous mark along all the casings is transferred. A plumb line is sufficient in vertical drillholes whereas for holes in directions other than vertical, orientation device as shown in Fig. 2 can be used to transfer the mark from one casing to another. Tests can be conducted in vertical, horizontal or even inclined drillholes.

6.10 The diameter of hole should be 76.2 mm. For determining the mismatch between the jack and the hole, the radius of the drillhole can be measured normally by an LVDT at 0.35 MPa or zero stress level. Table 1 can be used to calculate the minimum stress (Q_{hmin}) to maintain full contact as a function of hole radius mismatch α with poisson's ratio (v) as 0.25.

6.11 Schematic sketch of stress transfer in drillholes is shown in Fig. 3.

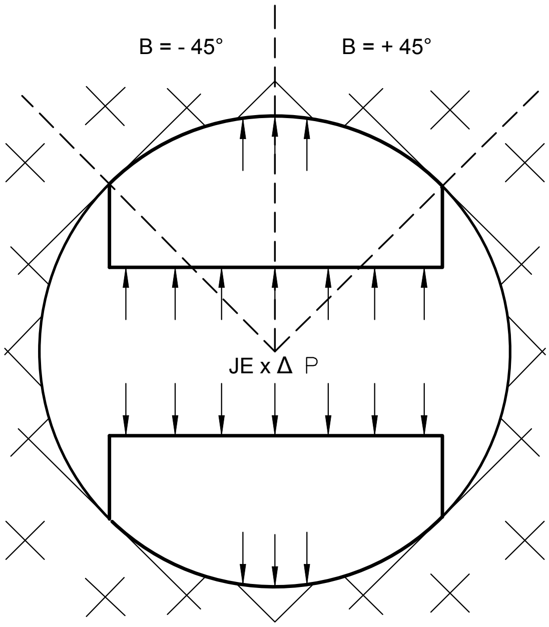

FIG. 3 SCHEMATIC SKETCH OF LOADING IN NX BOREHOLE JACK

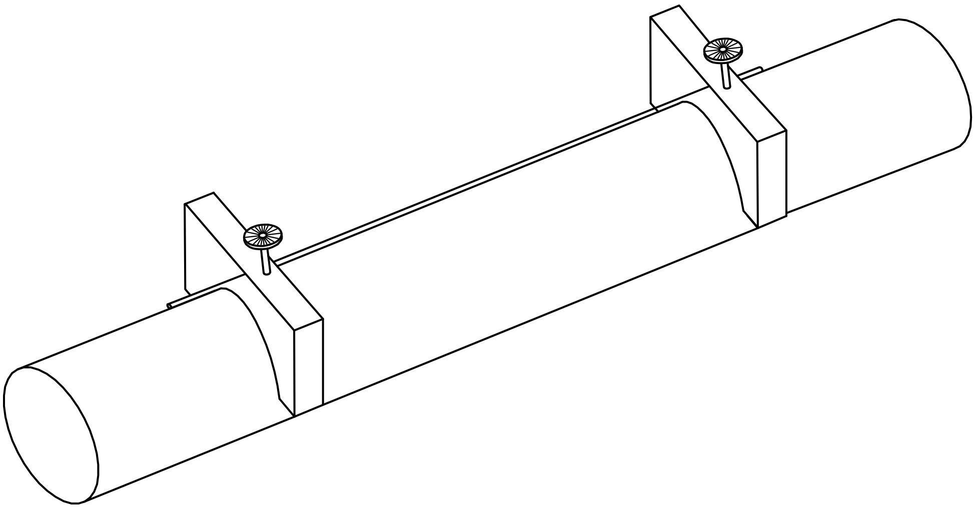

FIG. 2 MARKING GUIDE ON BX CASINGS

Table 1 Minimum Hydraulic Pressure to Ensure Full Contact as a Function of Hole Radius Mismatch a with Poisson's Ratio, υ as 0.25, and 2α = Hole Diameter – 76.2 mm

(*Clause* 6.10)

Sl No. (1)	$E_{theoretical}$ (GPa) (2)	Q_{hmin}/α (MPa/mm) (3)	$E_{theoretical}$ (GPa) (4)	Q_{hmin}/α (MPa/mm) (5)
i)	6.9	55	6.9	80
ii)	13.8	110	13.8	160
iii)	20.7	160	20.7	235
iv)	27.6	205	27.6	315
v)	34.5	250	34.5	395
vi)	41.4	290	41.4	475
vii)	48.3	330	48.3	555
viii)	55.2	365	55.2	630
ix)	62.1	400	62.1	710
x)	69.0	435	69.0	790

NOTES

1 For Oversize Holes: $Q_{hmin} = \dfrac{0.20\,\alpha\;30\times10^{6}\,E_{theoretical}}{30\times10^{6}\left(1-\nu^{2}\right)+0.91\,E_{theoretical}}$

2 For Undersize Holes: $Q_{hmin} = \dfrac{\alpha\;E_{theoretical}}{3.67\left(1-\nu^{2}\right)}$

6.12 The maximum load at which the test is to be conducted shall correspond to 1.2 to 1.5 times the anticipated maximum stress liable to be developed on account of the of the proposed structure. Test shall be conducted in five cycles with peak stress levels of 20 percent, 40 percent, 60 percent, 80 percent and 100 percent of maximum test pressure. Each time, the stress is applied up to the maximum stress level corresponding to that particular cycle and deformations at various incremental stress levels (1/5th to 1/10th of ultimate stress level) are recorded. Since, it is a cyclic loading test; therefore, the stress shall be brought down to the initial level in a manner similar to loading. Deformations at corresponding stress levels shall be recorded. At peak and initial stress levels, deformation shall be recorded after it stabilizes. Generally, 2 min time is sufficient enough for deformations to stabilize.

6.13 Creep characteristics of rock mass can also be studied at any particular stress level. The stress level is kept constant for the specified period as desired for studying the creep characteristics.

6.14 After the completion of test, stress *versus* deformation curves is plotted. The deformations of rock mass at peak stress level during loading and unloading are calculated. These deformations are used for the determination of modulus of deformation, E_{d} using total deformation, Δd during loading for any particular cycle and for determination of recovery modulus, E_{rec}, deformations, Δr recovered during unloading in the same cycle are used in the computations. For the sake of clarity, Fig. 4 can be referred.

6.15 Since deformations in the first cycle may not be true representative of rock mass due to crushing of asperities and adjustment of loading plates with the borehole walls, therefore, modulus values are determined for the successive cycles only.

6.16 Stress transferred to the rock mass depends on the rigidity of the plates and the number of pistons in the borehole jack. Therefore, transferred stress to the rock mass varies with the type of borehole jack.

7 INTERPRETATION OF TEST RESULTS

7.1 $E_{theoretical}$ can be estimated by reducing the core modulus obtained from laboratory test by a factor of 2.5.

7.2 Poisson's ratio, ν can be taken from laboratory test values. The equation for apparent modulus of rock mass is based on full platen/rock contact in a 76.2 mm diameter drillhole.

7.3 For full contact of the platens/rock, the following equation can be used to calculate the apparent modulus:

$$E_{calc} = 0.86 \times JE \times \left[\frac{\Delta P}{\Delta d / D}\right] T^{*}$$

where

0.86 = effect of finite test length.

JE = jack efficiency provided by the manufacturer, generally 93 percent for jack having twelve pistons (for hard rock) and 55 percent for jack having 3 pistons (for soft rock).

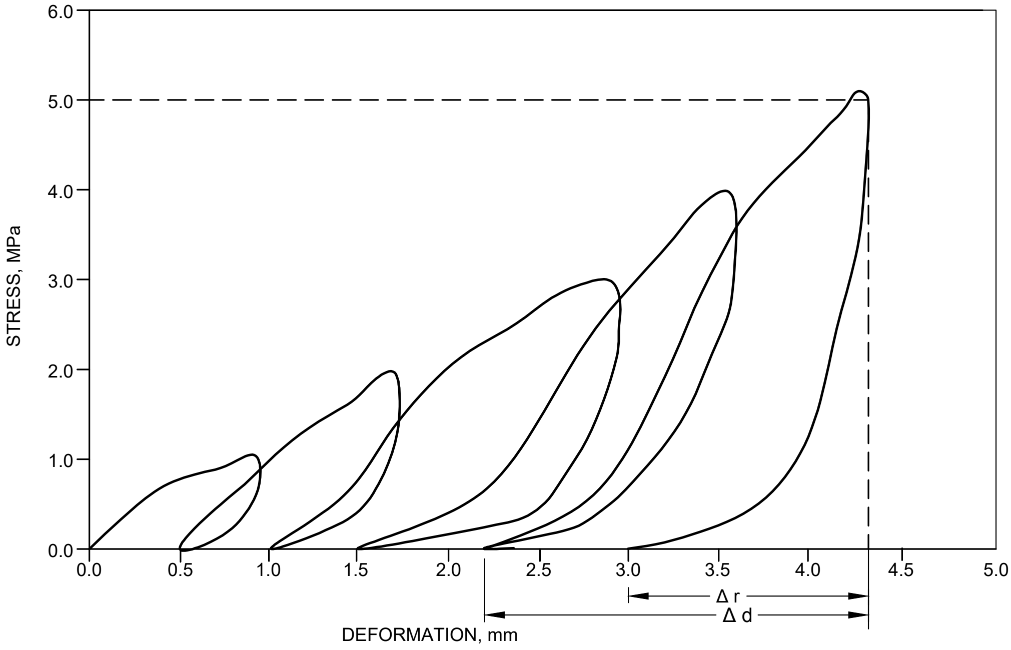

FIG. 4 TYPICAL CYCLIC STRESS *VERSUS* DEFORMATION PLOT

*T** = coefficient for full contact which depends on Poisson's ratio of rock as given in Table 2. Poisson's ratio of the rock can be taken from the laboratory tests on representative rock. If its value has not been determined in the laboratory, it may be considered between 0.20 and 0.30. Its value for different rock types shall be assumed as 0.20 for excellent rocks such as granite etc., 0.25 for gneiss, quartzite, etc, and 0.30 for mica schist, slates, etc.

ΔP = incremental stress.

Δd = average diametral displacement for an incremental stress of $\triangle P$; use $\triangle r$ for calculation of recovery modulus (E_{rec}) for the unloading as explained in Fig. 4.

D = diameter of drillhole.

Table 2 *T for Full Contact**

(*Clause* 7.3)

Sl No.	*v*	*T**
(1)	(2)	(3)
i)	0.1	1.519
ii)	0.2	1.474
iii)	0.25	1.438
iv)	0.3	1.397
v)	0.33	1.366
vi)	0.4	1.289
vii)	0.5	1.151

7.4 $E_{theoretical}$ can be obtained from E_{calc} using Fig. 5. Correction factor is negligible for E_{calc} less than 7 GPa; hence, E_{calc} is equal to $E_{theoretical}$.

8 REPORT

8.1 Report should include,

a) test results of different variants of rock;

b) geological details of the project as well as the drillholes the assumptions; and

c) details of test equipment and the test procedure including the computations.

8.2 The modulus can be compared with the core modulus from laboratory tests.

8.3 All the test results, stress deformation plots of the individual tests and interpretation of test data should be integral part of the report as these details define the stress-deformation behaviour of rock mass. A brief summary of recommended values should be given in the 'Abstract' section.

8.4 The reason for omitting any result or recommendation of the values for design should be clearly spelt out in the report.

8.5 Since modulus of rock is dependent on the applied stress, selection of ultimate stress shall be clearly defined and detailed in the report.

8.6 Apart from tabular form, results can be presented in graphical/histograms formats too. The photographs of adjacent exposed rock mass help the designers to know about the geological details.

9 APPLICATIONS OF MODULUS OF DEFORMATION

9.1 For design of structures in or on the rock mass using modulus of deformation of rock mass from borehole jack test, the points given in **9.1** to **9.4** are required to be taken care of.

9.2 Within the limit of elasticity, modulus of deformation of rock mass is stress dependent which means, higher the applied stress, greater will be the modulus of deformation. The test report should contain all the relevant data including geological details and test data so as to enable the designer to choose the appropriate value in design.

9.3 The modulus of deformation of rock mass also depends on the loading area. Therefore, spacing of joints plays a key role in modulus of deformation. The size of loading platen in borehole jack is fixed and may cover few joints only. In massive rock, there may be no joints within the zone of influence. The accuracy of placing the jack at the pre-specified test section depends on the core recovery. Therefore, scale effect may be considered using the results in the design of structure.

9.4 The borehole jack test provides static modulus of deformation of rock mass.

9.5 The rock being anisotropic in nature, direction of applied stress should also be taken into consideration.

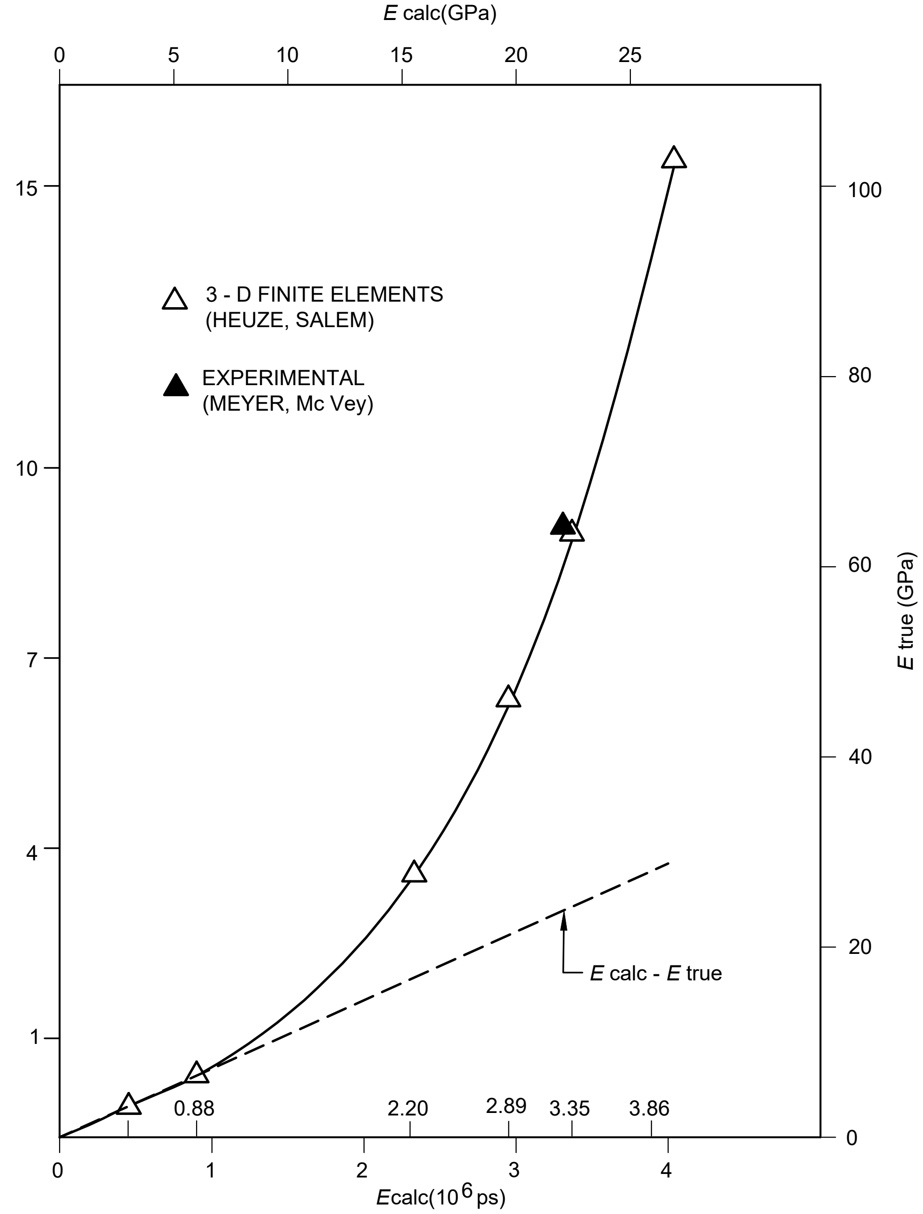

FIG. 5 CURVE FOR $E_{THEORETICAL}$ *VERSUS* E_{CALC}

ANNEX A

(*Foreword*)

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